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Solar Cycle Variations in IMF Intensity

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SOLAR CYCLE VARIATIONS IN IMF INTENSITY

by

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ABSTRACT

Annual averages of logarithms of hourly IMF intensities, obtained from geocentric spacecraft between November 1963 and December 1977, reveal the following solar cycle variation. For 2-3 years at each solar minimum period, the IMF intensity is depressed by 10-15% relative to its mean value realized during a broad nine-year period centered at solar maximum. No systematic variations occur during this nine-year period. The solar minimum decrease, although small relative to variations in some other solar wind parameters, is both statistically and physically significant.

INTRODUCTION

Determination of possible solar cycle variations in the mean interplanetary magnetic field intensity is important for studies of solar magnetism, of the relation between solar and interplanetary magnetic fields, and of geomagnetic activity and cosmic ray solar cycle variations. For example, a model in which the IMF intensity is largely due to solar polar magnetic fields would yield a brief minimum in the IMF intensity shortly after solar maximum, when the solar polar fields are weak and reversing, but would yield no other significant solar cycle variations. Svalgaard and Wilcox (1978) advocate such a view, although they suggest that an additional solar source (low latitude magnetic sectors) of IMF must be operative shortly after solar maximum to match the previously reported IMF observations.

Early searches for solar cycle variations in IMF intensity indicated a small increase in mean and modal intensities, and in the precent of high intensities, at solar maximum times relative to solar minimum (Hirshberg, 1969, 1973; Schatten, 1971; Neugebauer, 1975). These studies used data obtained between 1962 and 1969, and showed that IMP-1 (late 1963-early 1964) and IMP-3 (1965) IMF parameters were low relative to the 1962 Mariner-2 data and to the later data from various spacecraft.

Subsequently, King (1976) showed that yearly averaged IMF intensities exhibit no systematic variation over the extended period 1966-1974. Both Schatten (1971) and King (1976) pointed out that some of the apparent increase from the 1963-1965 IMF averages to the later averages resulted from the change of averaging sequences used in the IMP-1 and 3 data

relative to the later data. The emphasis of Schatten was that a physically real IMF intensity increase, of indeterminate amplitude, occurred between 1965 and 1966, whereas the emphasis of King was that the physical reality of such an increase had not been unambiguously demonstrated.

Several recent papers have appeared in which the lack of a solar cycle variation in the IMF intensity has been accepted (Feldman et al., 1977; Svalgaard and Wilcox, 1978; Smith, 1978).

The purpose of this brief report is to extend the analysis of King (1976) through 1977 and to demonstrate that a modest, but statistically significant, decrease in the IMF intensity occurred in the period 1975-1976. This decrease may be the counterpart of the decrease observed in 1963-1965 at a similar solar cycle phase.

DATA AND ANALYSIS

The IMF data used in this analysis through 1975 are as compiled in King (1977). In addition, approximately 5000 hourly averaged IMF intensities measured by IMP-8 (Ness and Lepping) during each year 1976 and 1977 are also included.

As is demonstrated in Burlaga and King (1979), IMF intensities tend to be log-normally distributed rather than normally distributed. Since it is desired to apply statistical confidence tests, which are readily available for normal distributions, logarithms of hourly IMF intensities (log B) will be used in this study.

Statistical confidence tests are directly applicable to samples with statistically independent elements. Our gappy time series of log B values yield the autocorrelation functions exhibited in Figure 1. (Note that, at

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lags $\gtrsim$ 10 hours, autocorrelations are a little greater for the 1973-1975 high speed stream dominated period. The autocorrelation times, at which the autocorrelation function falls to 0.5, are about 1.5 hours less for B than for log B, for each time interval.) These autocorrelations, which follow from the non-independence of data points, may be handled in the following confidence tests by using $N^* = N/F$ as the equivalent number of independent data points in a given average; here N is the actual number of data points and F is given by (Bell and Glazer, 1957)

$$F = 1 + \frac{2}{N} \sum_i n_i \rho_i,$$

where ρ_i is the autocorrelation function at lag i and n_i is the number of pairs of points with lag i, and where the sum is as required to encompass the significantly nonzero ρ_i.

For the data from which Figure 1 was constructed, F assumes the values 28.0 (1967-1969) and 30.5 (1973-1975). We shall use F = 29 for the rest of this study.

THE RESULTS

Figure 2 shows the annual averages of log B over the years 1963-1977. The error bars show the standard errors in the averages ($\sigma/\sqrt{N^*}$). The standard deviations (σ) in the 15 annual distributions of logarithms themselves constitute a sample of mean 0.178 and standard deviation 0.011. Figure 2 also shows the percent of the hours in each year in which the field intensity exceeds 10γ. Note that this percentage generally follows

the trend of the annual means, although this correlation is not perfect because of variations in annual σ values and because of deviations from log-normalcy in the IMF intensity distributions.

The trends discussed in the previously referenced papers are apparent in Figure 2. That is, there is a significant increase in field intensity between 1965 and 1966, and there is no systematic variation over the interval 1966 to 1974.

The primary new result reported here is that for the years 1975-1976 the mean log B is diminished by a statistically significant amount relative to the value ($\lesssim 0.76$) about which the 1966-1974 means varied. The 1977 mean seems to be recovering toward the more typical values.

Application of the "t test" reveals that the chances of the 1973 (typical of the 1966-1974 period) and 1975 sample means arising by chance from the same population is about 0.8%. Clearly the decreases at either end of Figure 2 are statistically significant. It is very unlikely that the decrease between 1974 and 1975 is due to instrumental effects or to data processing, in part because the decrease is separately visible in both IMP-8 and HEOS data. This finding supports the assertion of Schatten (1971) that a significant part of the 1965-1966 increase is physically real, since the two dips occur at nearly the same solar cycle phase. The extent to which the difference in the 1964-65 and 1975-76 $\langle \log B \rangle$ levels is due to the previously discussed IMP-1 and 3 data processing difference, as opposed to physical differences in the two solar minimum periods, is indeterminate.

Note that during the 1966-1974 period of no systematic variations in the log B annual means, there are two significant excursions from the 1966-1974 mean. There is an 18% chance that the 1970 and 1971 samples are

drawn from the same population, and an 11% chance for the 1973 and 1974 samples. Further the chance that the 1971 and 1974 samples are drawn from the same population is only about 0.2%. It is of interest to note that the weak 1971 dip occurs shortly after solar maximum; the relevance of this to the Svalgaard-Wilcox hypothesis discussed in the introduction is uncertain. (It should be noted that that hypothesis cannot explain a global minimum of IMF intensity at solar activity minimum.) It is also of interest to note that the 1974 increase in < log B > occurs during the year of greatest yearly averaged solar wind speed (Feldman _et al_., 1978). However it is clear by comparing the speed averages of Feldman _et al_. with the log B averages of this paper that no simple correlation between these averages exists.

SUMMARY

Statistically and physically significant decreases in mean IMF intensities have been observed at 1 AU within 7.25° of the solar equator, at the two most recent solar activity minimum periods. These IMF minima, of 2-3 years each, bracket a broad nine-year interval around the time of solar activity maximum in which annual mean IMF intensities exhibit "random" but no systematic variations. The amplitude of the IMF change from solar maximum to minimum is of the order of 10-15%, which is somewhat smaller than solar cycle variations in other solar wind parameters. (See, for example, the review of Bridge, 1976.)

Further studies are required to explain the amplitude, phase, and duration of the observed solar-minimum intensity decreases, in terms of both solar magnetic variations and variations in interplanetary dynamics following from variations in solar activity and coronal structure.

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FIGURE CAPTIONS

FIGURE 1 Autocorrelation functions for the 1967-1969 and 1973-1975 times series of log B values. Not visible on this scale is the fact that for lags up to 8 hours, the autocorrelation function for the earlier period slightly exceeds that for the later period.

FIGURE 2 Annual mean values of hourly averaged logarithms of IMF intensity. The horizontal bars indicate the portions of the years over which data are available. The vertical error bars are the standard errors in the means. The triangles indicate percentages of $B > 10\gamma$ hourly averages in each year.

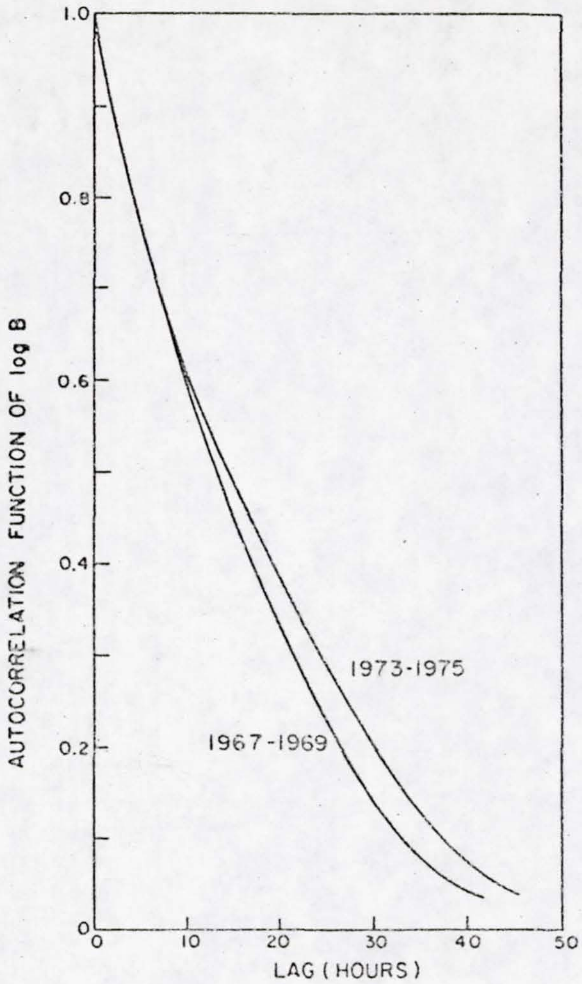

Figure 1

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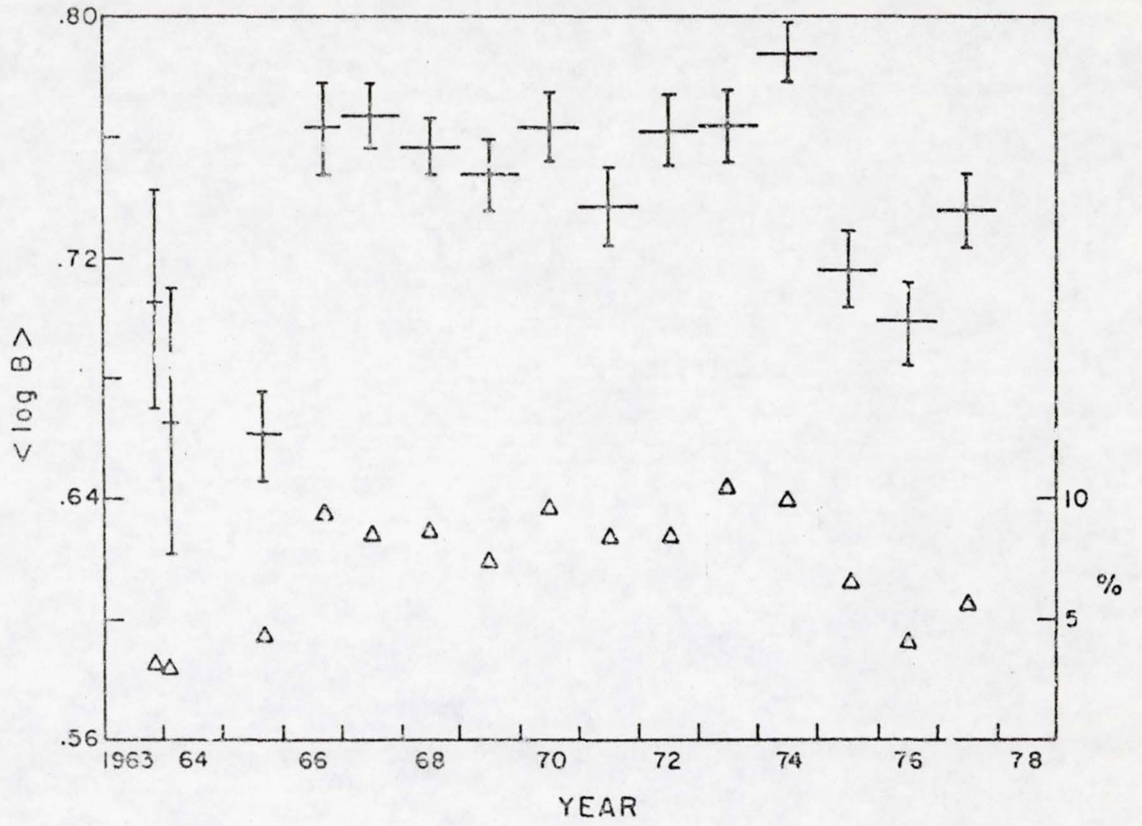

Figure 2

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